Comparisons among neutron-star mergers and heavy-ion collisions

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Neutron-star mergers:

3D phase diagrams:
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Charge Fraction $Y_Q = \frac{Q}{B}$ overview

- Heavy-ion collisions: $0.4 \rightarrow 0.5$
- Cold catalyzed neutron stars cores: $0 \rightarrow 0.15$
- Supernovae explosions and proto-neutron stars: $0.1 \rightarrow 0.5 \ (0.4)$
- Neutron-star mergers?
Merger in the QCD Phase Diagram

- Background: 2D \((T,n_B)\) CMF EoS \(Y_Q=Q/B=0.05\)
- Solve coupled Einstein-hydrodynamics system using (FIL)
- 3D \((T,n_B,Y_Q)\) CMF EoS with 1\(^{st}\) order phase transition for binaries with mass 2.9 \(M_{\text{sun}}\)
- Tracking maximum temperature \(\bullet\) and density \(\blacklozenge\)
More Phase Diagrams

- Tracking maximum temperature ● and density ●

- Increase in abs. value of charged chemical potential until phase transition, when it drops

- Decrease in charge fraction of core when quarks appear (not reaching heavy-ion/supernovae conditions)
3D QCD Phase Diagrams ($Y_S=0$)

- $T, \tilde{\mu}, Y_Q$ with charge fraction $Y_Q = Q/B = 0 \rightarrow 0.5$
  and Gibbs free energy per baryon $\tilde{\mu} = \mu_B + Y_Q \mu_Q$

- Larger $Y_Q$ (at fixed $T$) pushes the phase transition to larger $\tilde{\mu}$

- Changes due to $Y_Q$ effects on the EoS (particle population) on each side
3D QCD Phase Diagrams ($Y_S=0$)

Gibbs free energy per baryon

$$\tilde{\mu} = \mu_B + Y_Q \mu_Q$$
Slices of 3D QCD Phase Diagrams

\((Y_S=0, Y_S \neq 0 \text{ in black})\)

- For finite net strangeness \(Y_S \neq 0\), deconfinement takes place at larger free energy/baryon chemical potential.
For finite net strangeness $Y_S \neq 0$, isospin and charge fraction relation is not trivial $Y_I = Y_Q - 0.5 + \frac{1}{2} Y_S$. 
Chemical Equilibrium Lines

- Leptons in chemical eq. with baryons/quarks $\mu_Q = \mu_{e,\mu}$
- Charge neutrality $Y_Q = Y_{\text{lepton}}$, finite strangeness $Y_S \neq 0$
Conclusions and Outlook

• Astrophysics provides an ideal testing ground for nuclear physics

• Conditions created in neutron-star mergers are unique ($Y_Q$, $Y_I$, $Y_S$, leptons, S/B...)

• We need to be careful when comparing deconfinement within different scenarios

• $Y_Q$, $Y_I$ affect significantly the deconfinement to quark matter: $\mu_B$ can change by up to 130 MeV and $\mu_{Q,I}$ by up to 330 MeV

• Model dependency is hard to quantify: more realistic models are needed